



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
WASHINGTON, D.C. 20546

NRO-JPL



OCT 29 1979

REPLY TO  
ATTN OF: GP

NST-44  
TO: ~~KSC~~ Scientific & Technical Information Division  
Attn: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General  
Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code KSI, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No.

3,352,774

Government or  
Corporate Employee

Anacut Engineering Co.  
Chicago, IL

Supplementary Corporate  
Source (if applicable)

NASA Patent Case No.

XNP-8835

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:

YES ☒

NO ☐

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words "...with respect to an invention of ..."

*Bonnie L. Henderson*

Bonnie L. Henderson

Enclosure

① The serial no. for patent 3,352,774 is 534,931  
filed 1-17-66 and issued 11-14-67.

② This patent is a divisional application  
of U.S. Serial No. 90,438 filed 2-20-61 and  
now patent no. 3,257,300, and issued 6-21-66.



Nov. 14, 1967

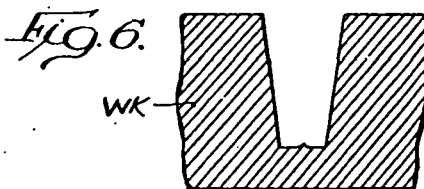
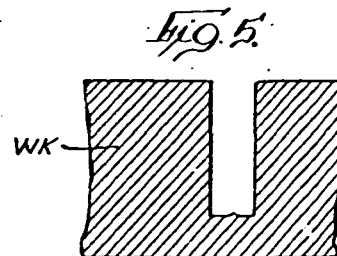
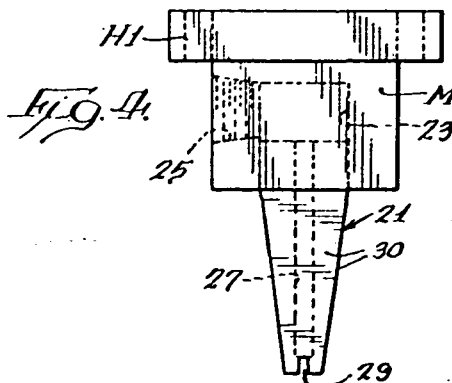
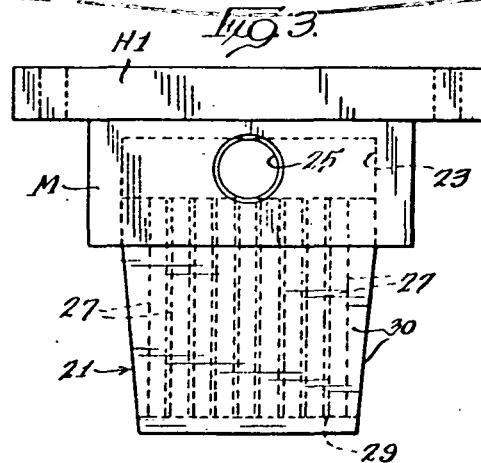
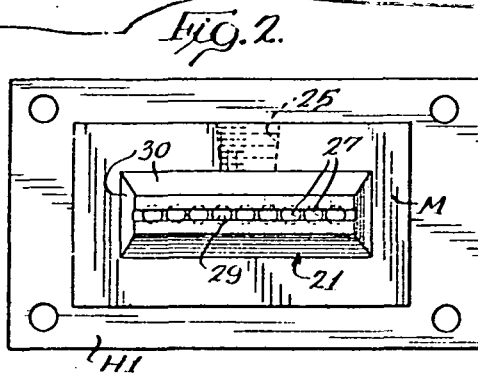
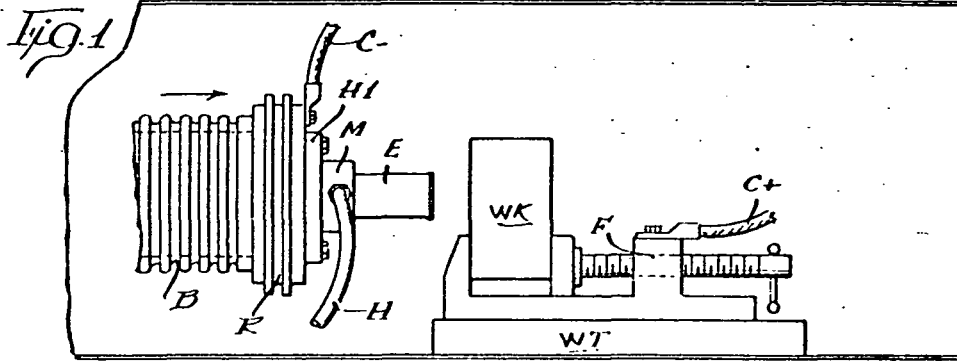
L. A. WILLIAMS

XNP-8835  
3,352,774

APPARATUS FOR ELECTROLYTICALLY TAPERED OR CONTOURED CAVITIES

Original Filed Feb. 20, 1961

2 Sheets-Sheet 1



INVENTOR:  
Lynn A. Williams  
BY  
Shadolph, Love & Rogers  
Attys

Nov. 14, 1967

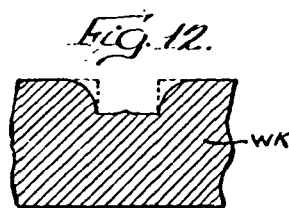
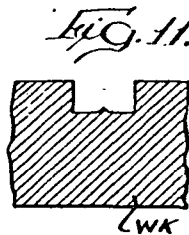
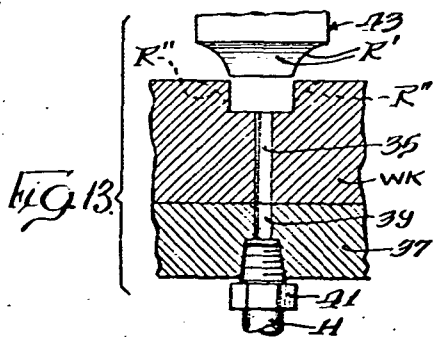
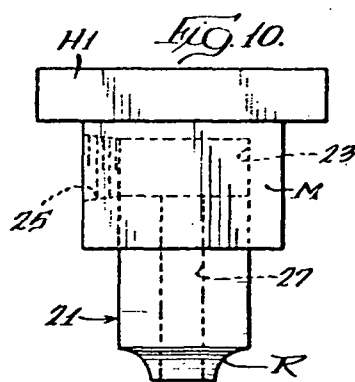
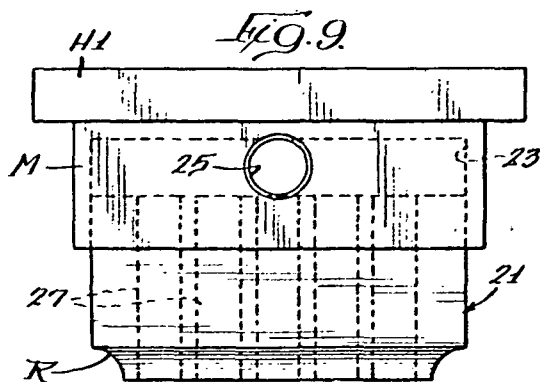
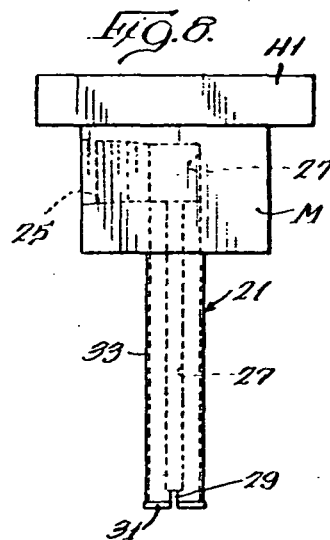
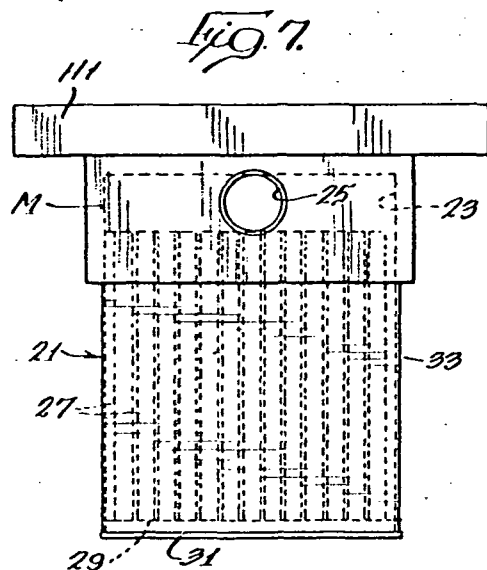
L. A. WILLIAMS

3,352,774

APPARATUS FOR ELECTROLYTICALLY TAPERED OR CONTOURED CAVITIES

Original Filed Feb. 20, 1961

2 Sheets-Sheet 2



INVENTOR:  
Lynn A. Williams  
BY  
Gladolph, Love & Rogers  
Attys

1

3,352,774

## APPARATUS FOR ELECTROLYTICALLY TAPERED OR CONTOURED CAVITIES

Lynn A. Williams, Winnetka, Ill., assignor to Anocut Engineering Company, Chicago, Ill., a corporation of Illinois

Original application Feb. 20, 1961, Ser. No. 90,438, now Patent No. 3,257,300, dated June 21, 1966. Divided and this application Jan. 17, 1966, Ser. No. 534,931.  
3 Claims. (Cl. 204-224)

This application is a division of application Ser. No. 90,438, filed Feb. 20, 1961, entitled, "Method for Electrolytically Forming Tapered or Contoured Cavities," issued into Patent No. 3,257,300, dated June 21, 1966.

This invention relates to electrodes for electrolytic shaping.

Also pertinent are the following applications of Lynn A. Williams all of which were copending with the parent application: Ser. No. 772,960, filed Nov. 10, 1958, entitled, "Electrolytic Shaping," issued into Patent No. 3,058,895, dated Oct. 16, 1962; Ser. No. 814,450, filed May 20, 1959, entitled, "Electrolytic Hole Sinking," issued into Patent No. 3,002,907, dated Oct. 3, 1961; Ser. No. 844,706, filed Oct. 6, 1959, entitled, "Electrolytic Removal of Work Materials," now Patent No. 3,276,988; Ser. No. 849,595, filed Oct. 29, 1959, entitled, "Electrode for Electrolytic Shaping," issued into Patent No. 3,019,178, dated Jan. 30, 1962; Ser. No. 853,194, filed Nov. 16, 1959, entitled, "Apparatus for Electrolytic Hole Sinking," issued into Patent No. 3,120,482, dated Feb. 4, 1964; Ser. No. 35,646, filed June 13, 1960, entitled, "Electrode for Electrolytic Shaping," issued into Patent No. 3,123,545, dated Mar. 3, 1964; Ser. No. 35,647, filed June 13, 1960, entitled, "Electrolytic Cavity Sinking Apparatus and Method," issued into Patent No. 3,196,093, dated July 20, 1965; and Ser. No. 36,314, filed June 15, 1960, entitled, "Electrolytic Shaping Apparatus and Method," now Patent No. 3,235,475.

A principal object of this invention is to provide equipment for the formation of cavities having tapered or contoured side walls with a smooth and in some instances with a high finish.

Another object is to provide electrodes usable in electrolytic cavity sinking to carry out the objective of the immediately preceding paragraph.

Another object is to facilitate the manufacture of suitable tool electrodes for forming such cavities.

Other objects and advantages will appear from the following description taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a schematic view in elevation of the work area of apparatus used in the practice of this invention;

FIG. 2 is a frontal view showing the working tip of a wedge electrode of this invention;

FIG. 3 is a side elevation of the electrode of FIG. 2;

FIG. 4 is an end view of the electrode of FIG. 2;

FIG. 5 is a sectional view of a workpiece showing a preliminary roughing cut;

FIG. 6 is a similar view of the same workpiece shown in FIG. 5 after finishing the cut to produce tapered side walls;

FIG. 7 is a side elevation of an electrode for forming a slot as a first step in the practice of the invention;

FIG. 8 is an end view of the electrode of FIG. 7;

FIG. 9 is a side elevation of a finishing electrode;

2

FIG. 10 is an end view of the finishing electrode of FIG. 9;

FIG. 11 is a sectional view of a workpiece with a roughing slot formed by the electrode of FIGS. 7 and 8; FIG. 12 is a sectional view of the same workpiece after it has been contoured by the electrode of FIGS. 9 and 10; and

FIG. 13 is a view, partly in section, of a modified arrangement wherein a solid contouring electrode is used with the electrolyte being introduced through a hole in the workpiece.

In some instances, it is desired to produce cavities in which the side walls are not straight but, rather, are tapered or contoured, and it is desirable that these should be produced with accuracy at high speed, and that they should have a high degree of polish or smooth finish. While it is possible to produce contours in workpieces by the methods shown in the above identified applications and the patents issued thereon, it is difficult to produce good accuracy and smooth finish when the surface to be formed deviates more than about 45 to 60 degrees from a plane normal to the direction of advance of the electrode, and this invention is concerned primarily, though not exclusively, with this kind of situation. But, as will be seen, the invention may also be used to produce very smooth surfaces which are substantially normal to the path of advance of the electrode. This is shown, for example, in the electrode of FIGS. 9 and 10 and in the workpiece of FIG. 12.

In the above identified applications and patents the discovery was shown that by maintaining the electrolyte under high pressure and, at the same time, maintaining high electrolyte velocity in the work gap a high surface finish could be induced in the work material, and this basic discovery is used in this invention. (See FIG. 24 and the related descriptive matter of the above identified application Ser. No. 772,960, now Patent No. 3,058,895.) In that application and patent there was disclosed the production of a high finish by the confinement of the electrolyte by use of an external restriction made of neoprene or rubber sealing rings. In the instant invention the sealing, in effect, is accomplished by the electrode itself, as will more fully appear in the following description.

Briefly, it has been found that if the electrode is arranged in such a way as to cause always a kind of outwardly wedging action against the work material, thereby tending constantly to confine the electrolyte, to maintain its pressure, and to maintain high velocity, then it is possible to secure close conformation of shape between the cavity in the workpiece and that on the electrode. And, at the same time, it is possible to produce a bright, specular finish even though the electrolyte solutions used are not of the kind ordinarily regarded as having electropolishing characteristics.

Referring to the drawings, FIG. 1 shows schematically the general configuration of the apparatus. An electrode E is mounted to a manifold M, which is fed with a hose H with electrolyte under a pressure of 100 to 300 p.s.i. at the manifold and at the entrance to the electrode. The manifold M is mounted in turn to a holder H1 which is fastened to a front plate of a ram R. The front plate is electrically insulated from the body of the ram, and the ram itself is protected against electrolyte by a collapsible boot B. Direct current of a voltage not appreciably greater than about 18 volts is supplied from a source of the type

disclosed in the copending application of Lynn A. Williams, Ser. No. 436,383, filed Dec. 23, 1964, entitled, "Control and Operating System for Electrolytic Hole Sinking," and now abandoned, by two cables C- and C+, indicating the polarity arranged to make the work an anode. The machine is fitted with a worktable WT on which may be mounted a fixture F, and to this the work WK is fastened with a clamp or vise. The entire work area is surrounded by an enclosure, which is intended to prevent the undesirable exit of splatter and spray. However, the work enclosure should be provided with vents and exhausted by a power blower to prevent the accumulation of hydrogen or unpleasant or noxious gases. It should be understood that the ram is arranged to be advanced under a positive drive at a predetermined fixed rate in the direction of the arrow toward the work, thereby moving the electrode linearly into the workpiece. A more detailed description of the type of apparatus which may be used is shown in the copending application of Lynn A. Williams, entitled "Electrolytic Cavity Sinking Apparatus and Method," Ser. No. 73,154, filed Sept. 2, 1960, and now issued into Patent No. 3,275,543, dated Sept. 27, 1966.

FIG. 2 shows one form of electrode used in the practice of the invention. It consists of an electrode proper 21, which is made of copper and is mounted in the manifold member M, which, in turn, may be either fastened to or made integrally with a holder plate H1. The manifold M is recessed as shown at 23, and provision is made for connection of a hose through a screw-threaded opening 25. The electrode 21 conforms to the shape of the recess 23 in the manifold, and may be fastened into it by any suitable means, for example, by brazing or soldering.

The electrode proper 21 is arranged to feed electrolyte from the recess 23 of the manifold to its working tip by a plurality of feed holes or passages 27. These should be drilled as conveniently close together as is possible without breaking out from one hole through the land into the next. In an electrode having a working tip with a width of the order of  $\frac{1}{4}$ ", the holes should be about  $\frac{1}{8}$ " in diameter, and, in general, the more open and free the passage for electrolyte the better. The holes 27 are not carried through all the way to the working tip of the electrode but terminate about  $\frac{1}{8}$ " to  $\frac{1}{4}$ " above it, where they are intersected by a transverse slot 29 which is milled into the end of the electrode in such a way as to communicate with the holes 27. The slot may be about  $\frac{1}{16}$ " wide for an electrode of this size. The slot 29 should be deep enough so as to smooth out the flow from the several holes 27, so that the electrolyte issues smoothly through the slot with a minimum reflection of the pattern of holes through which it previously passed.

This electrode is not insulated either on its sides or on its ends, but is left bare for the purpose of producing tapered side walls 30. The electrode may be used in either of two ways. Either it may be simply advanced into a raw piece of work, using the maximum penetration rate which is obtainable, or, preferably, it may be used to enlarge a cavity previously made by a slotting electrode; for example, one like that shown in FIGS. 7 and 8 or as shown in one or more of the previously identified applications. A cut of this preliminary kind is shown in FIG. 5. There is no basic reason why it could not be produced by conventional machining as well as by electrolytic means, although ordinarily formation of cavities of this sort can be accomplished more quickly by use of electrolytic machining techniques than by conventional methods. The width and length of the preliminary cut as shown in FIG. 5 should be about the size of the working tip of the tapered electrode shown in FIGS. 2, 3 and 4.

The method of advancing the tapered electrode directly into a workpiece without making a preliminary cut can be carried out where the taper on the sides and ends of the electrode is sufficiently great (say,  $30^\circ$  from the line of advance of the electrode). As the angle of taper becomes less, a point is reached where it is necessary to

make a preliminary cut like that shown in the workpiece of FIG. 5. This is for the reason that it is not possible to maintain a sufficiently fast rate of frontal advance into the work to keep the tapered sides sufficiently close to the work material, which, of course, is being electrolytically removed in a generally sideward direction. By making the preliminary cut as shown in FIG. 5 it becomes possible to advance the electrode at a rate which is high enough to keep up with rate of sideward removal, as there is no concern with the frontal removal at the tip of the electrode. In addition, the cavity shown in FIG. 5 aids in spreading the electrolyte uniformly over the entire side surfaces, for the cavity forms a kind of plenum which quickly fills with electrolyte and, thereafter, induces a uniform flow which is helpful in producing accurate work. FIG. 6 shows the shape of the tapered cavity formed in the same workpiece shown in FIG. 5 by using the electrode of FIGS. 2, 3 and 4.

It is important that a very copious supply of electrolyte be provided, and, accordingly, the supply hose H should be large enough to deliver the full volume without substantial loss of pressure, and, similarly, the manifold recess 23 should be adequate in size to assure full flow and uniform distribution.

Referring to FIGS. 7, 8, 9 and 10, a somewhat different application of the same invention is shown. FIGS. 7 and 8 show a simple electrode for making a rectangular cavity. The electrode proper 21 may be made like other electrodes of copper. It is fitted into a recess 23 in a manifold M which, in turn, is fastened to a holder or mounting plate H1. The cavity 23 is fed by an opening adapted to receive a hose connection as at 25. The electrode proper is drilled with feed holes or passages 27, which are closely spaced as previously described in connection with the electrode of FIGS. 2, 3 and 4. A slot 29 is milled into the electrode near its tip, and then, an additional member serving as a flange plate 31 is fastened to the body of the electrode by brazing or soldering. This additional flange plate is arranged to project beyond the body of the electrode by about .010" to .030" with the purpose of providing clearance for insulating material 33, which is applied to the body of the electrode to prevent excessive side action.

After this electrode of FIGS. 7 and 8 has been used to form a cavity like that shown in section in FIG. 11, then the electrode of FIGS. 9 and 10 is used in order to modify the shape of the cavity to provide radii on all of the side walls. This electrode of FIGS. 9 and 10 is made in substantially the same way as the electrodes previously described herein with like reference indicia referring to similar parts. Here, however, it is not necessary to provide any slot, but, instead, quite large feed holes 27 are used, and these pass directly through the body of the electrode 21 to feed electrolyte into the work area.

Unlike the preceding electrodes, this type is machined to a shape to provide a full radius as shown at R. This, of course, may be any contour which is desired and may be either straight or curved as the work requirements dictate.

After forming the cavity of FIG. 11, then the electrode of FIGS. 9 and 10 is positioned so that the working tip of this electrode registers with the previously formed cavity. It is not critical that the working face should have identically the same contour as the cavity, but the deviation should not be excessive and, particularly important, there should not be any place where the cavity is so much larger than the finishing electrode that any large amount of the electrolyte will escape through the gap which would thus be formed. Except for this, however, close conformity is desirable but not necessary.

After positioning the electrode of FIGS. 9 and 10 with respect to the pre-existing cavity, it is then advanced at a fairly rapid rate into the work until it has reached a depth where its working tip is close to the bottom of the previously formed cavity. If this is done rapidly, the result will be to form an accurate contour and to induce a very high finish on the work material.

In practice, an electrode like that of FIGS. 7 and 8 has been made as a roughing electrode, its dimensions being 2" in length and  $\frac{3}{8}$ " in width. The cavity like that shown in FIG. 11 was produced with an infeed rate of advance of .100" per minute using a direct current of 14 volts and an electrode pressure of about 200 p.s.i. The cavity in the workpiece was carried to a depth of .200".

Subsequently, an electrode like that of FIGS. 9 and 10 was applied, using a feed rate of .200" per minute, an electrolyzing current at a voltage of 13 volts and a total penetration to a depth of .187".

The electrolyte used was that described in the above mentioned application, Ser. No. 772,960, issued into Patent No. 3,058,895.

Another electrolyte can be made of four pounds of salts to each gallon of water, the salts being in the following ratio:

	Parts
Potassium chloride	3
Potassium nitrate	1
Rochelle salts	1
Potassium citrate	1

For some kinds of work a solution of about ten percent of sodium chloride can be used satisfactorily. This is particularly applicable for ordinary tool steels as distinguished from the higher nickel alloys found in stainless steel and high temperature super-alloy materials. For the latter the electrolyte of the preceding paragraph is preferred.

In FIG. 13 there is illustrated an arrangement for forming a tapered or contoured cavity without using a hollow electrode. The workpiece WK is initially formed with a through cavity 35 by electrolytic or conventional machining techniques. The workpiece is mounted or clamped in a fixture or bracket 37 having one or more passages 39 therethrough adapted to be placed in communication with the workpiece cavity 35. If the workpiece cavity is large or elongate then two, three or more fixture passages 39 fed from a manifold similar in function to the manifold M of FIGS. 2 to 4, 9 and 10, should be provided. The passage or passages 39 (or manifold if one is used) is connected to the previously mentioned electrolyte supply source by the hose H and fitting 41 so that a copious supply of electrolyte under pressure may be obtained.

The electrode 43 is similar in configuration (for illustration purposes only) to that shown in FIGS. 9 and 10 but is made of a solid block of copper or other suitable material and is mounted directly upon the holder H1 to be connected into the electrolyzing power circuit in a manner to be cathodic. It is formed with contouring radii R' which are adapted electrolytically to form contoured surfaces R'' on the workpiece WK.

With the electric current turned on and electrolyte being supplied to the rough workpiece cavity 35, the electrode 43 is advanced into the work with a positive feed and at a constant rate. The rough cavity in the workpiece forms a plenum ahead of the advancing electrode and as the electrolyte escapes from the cavity between the electrode surfaces R' and the workpiece the latter is electrolytically eroded to the shape of the surfaces R'' to have a smooth finish and, depending upon the character of the workpiece material, perhaps a high specular finish.

It should be appreciated that the essential difference between the first two forms of the invention and the last is the direction of electrolyte flow. In all three there is formed in the workpiece a kind of plenum to which the electrolyte is fed under high pressure and from which it escapes at high velocity between the active faces of the electrode and those portions of the workpiece being electrolytically eroded.

It has been found practical, for example, to use this method in making hollow bolts each having a recessed hexagonal socket, like an Allen screw. This can be done

by electrolytically sinking a hole through the length of the bolt. Electrolyte is then introduced into the bottom of the hole and a hexagonally shaped electrode is fed into the head of the bolt cavity to enlarge it and to change its shape from round to hexagonal.

While three rather simple forms of the invention have been illustrated and described, it should be understood that many variations and complications are possible. Thus, for example, while a wedge shaped electrode is shown in FIGS. 2, 3 and 4 having a rather regular shape, other electrodes have also been used in which, while the same general tapered configuration was employed, the actual shape was the rather complex shape existing between two blades of a turbine wheel, the blades themselves having a twist or camber and, at the same time, a constantly changing section. In this instance, a preliminary, straight-sided cut was made into a disc of material at a point roughly representing the midpoint between two of the blades. Subsequently the wedge shaped electrode formed to produce the interblade cavity was introduced at a high rate of feed in order to shape and finish the convex side of one blade and, concurrently, the joining concave side of the next blade.

The essential idea is that the electrode should be one in which its section grows larger as it is advanced into the work so as to remove material by side action while at all times forcing the electrode into the cavity to maintain close spacing between the electrode and the work, a spacing of the order of 0.15" or less while, at the same time, maintaining electrolyte pressure of the order of 100 p.s.i. or more and, at the same time, maintaining high velocity of electrolyte flow. The rate of advance necessary to bring about these conditions will, of course, be determined by the taper. If the taper is shallow, then the electrode may have to be advanced very rapidly, as rapidly, for example, as an inch per minute or even more. On the other hand, if the taper is steeper then a slower rate of advance will maintain the desired condition. In the case of the electrode shown in FIGS. 9 and 10, it has been found in practice that it is not necessary to change the rate of advance even though the rate of taper changes. Apparently, the feed rate of .200" per minute is a reasonable compromise between the rate one might use for the very slight degree of taper at the tip itself and the much greater taper approaching, in fact, a surface normal to the line of advance at the upper limit of the radius portion. Theoretically, it might be desirable to advance an electrode of this kind at first more rapidly and then more slowly, but, as has been said, it was not found to be necessary in fact in this particular instance.

Many other variations and changes may be made without departing from the spirit and scope of the invention, and the scope of the invention is to be determined from the scope of the following claims.

What is claimed as new and desired to be secured by United States Letters Patent is:

1. In an electrolytic machining apparatus for forming tapered or contoured cavities in an electrically conductive and electrochemically erodible workpiece, the apparatus having means for supporting the workpiece and an electrode for movement relatively toward each other, means for pumping an electrolyte between the workpiece and the electrode, and means connected for passing an electrolyzing current between the workpiece and the electrode, the electrode comprising an electrode body made of a conductive material having at one end thereof a working tip, electrolyte passages extending through said body from the opposite end thereof to said tip, a transverse slot in said tip interconnecting said passages, the external surface of said body flaring outwardly away from said tip to be shaped complementally to the contour of the cavity to be formed, means for forming a plenum chamber secured to said body at said opposite end and in communication with said passages, and an inlet connection to said plenum chamber.

3,352,774

7

2. The combination set forth in claim 1 wherein said electrode body has an increasing cross-sectional area away from said tip.

3. The combination set forth in claim 2 wherein said cross-sectional area increases radially.

5

# References Cited

## UNITED STATES PATENTS

1,787,247	12/1930	Grow	219-69 X
2,059,236	11/1936	Holslag	219-69 10
2,101,214	12/1937	Everett	303-1
2,650,979	9/1953	Teubner	219-59
2,750,332	6/1956	Miller	204-15

8

2,909,641	10/1959	Kucyn	219-69
3,051,638	8/1962	Clifford et al.	204-143
3,095,364	6/1963	Faust et al.	204-143
3,144,541	8/1964	Hill	219-69

## FOREIGN PATENTS

583,609	9/1933	Germany.
964,556	5/1957	Germany.
141,489	4/1920	Great Britain.
553,074	12/1956	Italy.

JOHN H. MACK, *Primary Examiner.*

W. VAN SISE, *Assistant Examiner.*